Appendix 7

civil defense Technical Bulletin

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RADIOLOGICAL DEFENSE SERIES

A DIGEST OF TECHNICAL INFORMATION

RADIATION PHYSICS AND BOMB PHENOMENOLOGY

This is one of a series of technical bulletins on civil defense against the radiological effects of nuclear weapons

This bulletin describes briefly the structure of the atom, how its energy is released in nuclear weapons, and methods of detection and measurement of nuclear radiations.

Structure of Matter

All matter is made up of atoms and combinations of atoms which unite chemically to form molecules. An atom is the smallest unit that retains the properties of an element or can enter into a chemical reaction. For example, common salt, sodium chloride (NaCl), is a combination of one atom of sodium (Na) and one atom of chlorine (Cl). Molecules of single elements may be single atoms or combinations of atoms. For example, one atom of oxygen is represented by O, but the normal oxygen molecule exists as a combination of two atoms, O_2.

Until recently the total number of known elements was thought to be 92, with hydrogen (H) the lightest, and uranium (U), the heaviest. Now, 101 elements have been identified.

All atoms except ordinary hydrogen contain three primary particles, the neutron, proton, and electron. Ordinary hydrogen does not contain a neutron. See Table 1 for characteristics of these particles.

Table 1—Characteristics of Atomic Particles

Name	*Symbol*	*Electrical Charge*		*Mass*
Electron	e	Negative	−1	0.000548 mu*
Proton	p	Positive	+1	1.007575 mu
Neutron	n	None	0	1.00893 mu

*(An atomic mass unit (mu) is 1.6×10^{-24} grams)

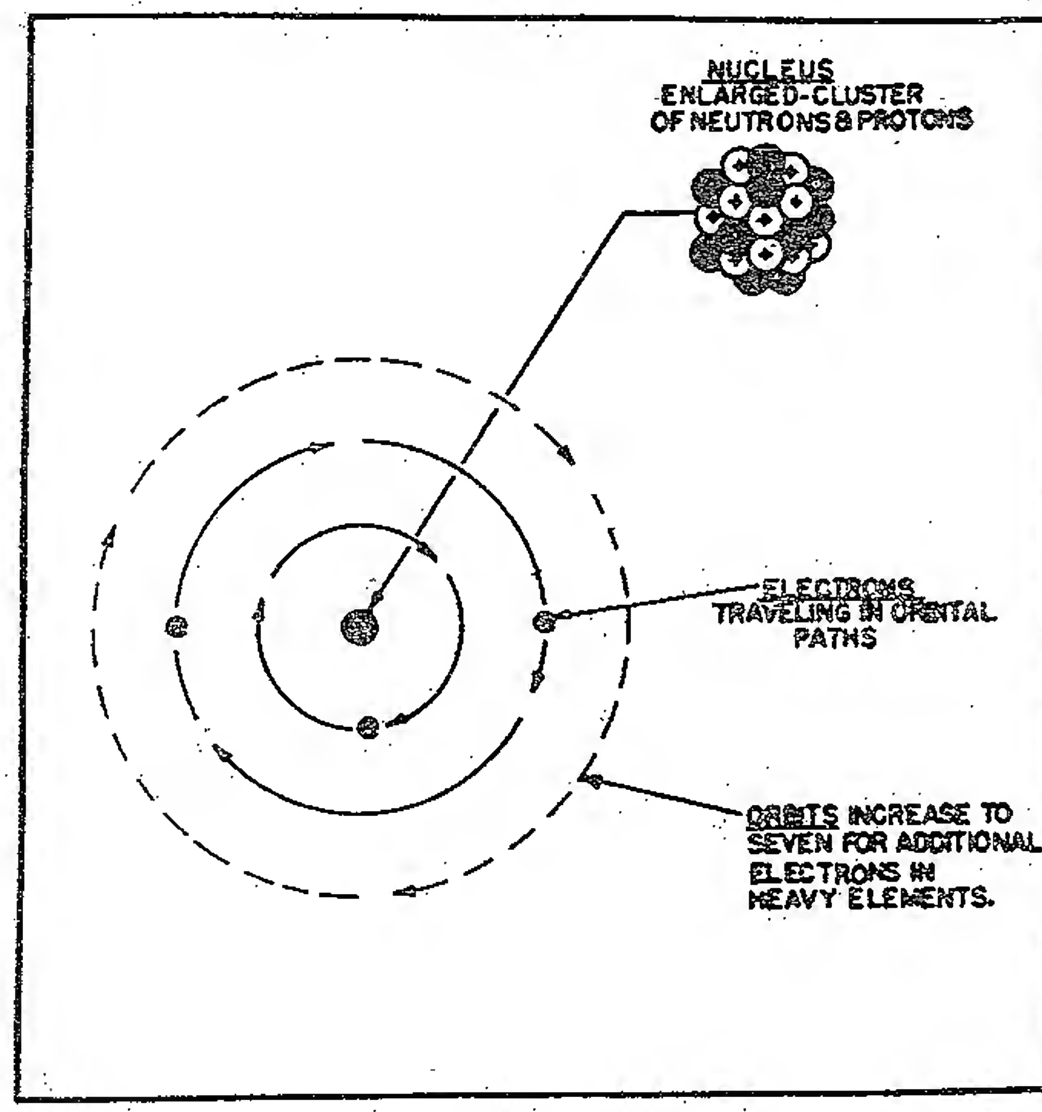

Figure 1—Diagram of an Atom.

The atom may be represented as a solar system consisting of a heavy central mass, the nucleus, with one or more electrons traveling in orbits around it. (Fig. 1). The atomic nucleus contains combinations of protons and neutrons. These combinations and the number of electrons vary with the element. To be electrically neutral, an atom must contain the same number of positively charged particles (protons) in the nucleus as negative particles (electrons) in its orbits. The removal of an electron from the orbit produces an ion pair. The free electron is the negative ion and the remaining portion of the atom, the positive ion. The average radius of an atomic nucleus is about 10^{-12} centimeters, and the atom 10^{-8} centimeters.

Discussion of atomic structure will be simplified by some definitions and symbols that are commonly used.

Z—atomic number. Number of protons in the nucleus of an atom. This number identifies an element. As an example, all atoms of sodium (Na) have a Z number of 11.

A—mass number. Sum of the proton and neutrons in the nucleus of an atom.

N—neutron number. Number of neutrons in the nucleus of an atom.

FEDERAL CIVIL DEFENSE ADMINISTRATION

Isotopes of an element. Forms of the element having the same number of protons in the nuclei, but differing in the number of neutrons. Isotopes of an element have almost identical chemical properties. Any isotope may be represented by the following expression:

$$_{Z}X^{A}$$

where X indicates the element. Examples of 2 isotopes of lithium, $_3Li^6$ and $_3Li^7$, are diagrammed in Fig. 2.

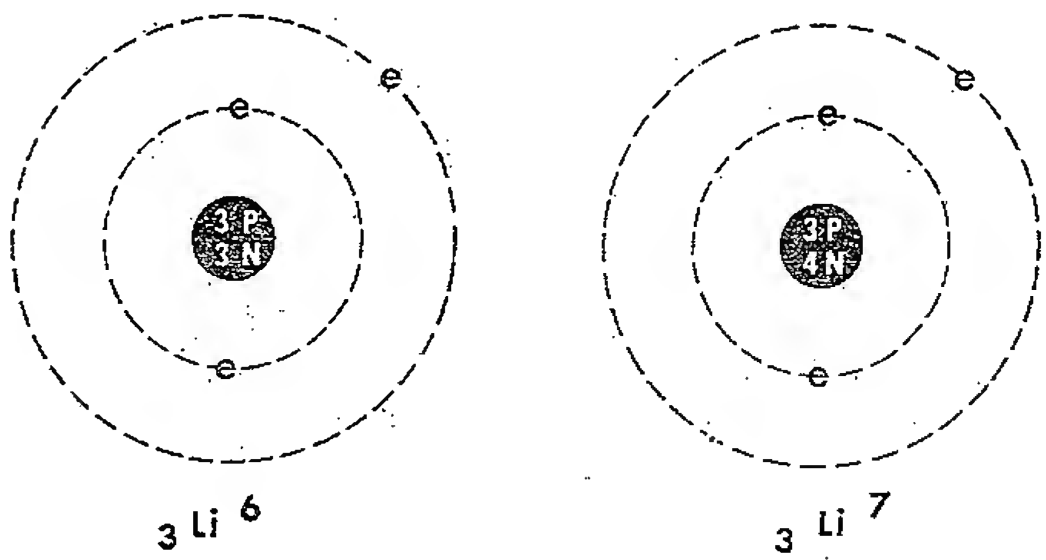

Figure 2—Diagram of Lithium Isotopes.

The difference between these two isotopes is one additional neutron in $_3Li^7$. Both are stable and are mixed in such proportion in nature that the average atomic weight is 6.94.

Radioactivity

Nuclear radiation is energy spontaneously released by an unstable (radioactive) nucleus to attain a more stable state. In certain cases this will result in transmutation — the changing of one element into another.

Some isotopes are naturally radioactive. Also radioactive isotopes may be artificially produced by subjecting a stable nucleus to bombardment by nuclear missiles such as alpha particles, neutrons, or protons. For example, when stable cobalt is bombarded by neutrons having the proper energy, a radioactive isotope of cobalt is formed as shown in the following nuclear equation:

$$\underset{\text{Stable}}{_{27}Co^{59}} + {_0n^1} \longrightarrow \underset{\text{Radioactive}}{_{27}Co^{60}}$$

Naturally occurring or artificially produced radioactive isotopes emit one or more of three types of radiation. Two of these are particulate—alpha and beta particles; the third is electromagnetic—gamma rays. Alpha particles are positively charged and consist of two protons and two neutrons. Beta particles are high speed electrons. Gamma rays are similar to light and heat waves, but are more energetic. The five senses are unable to detect the presence of nuclear radiation, therefore, a person can become seriously exposed without being aware of it.

The three types of nuclear radiation can be identified by their behavior in a magnetic field. Those slightly deflected by the field are alpha particles, those more easily deflected in the opposite direction, beta particles, and those unaffected, gamma rays. Table 2 summarizes their characteristics.

Table 2—Characteristics of Nuclear Radiation

Radiation	*Symbol*	*Type*	*Mass*	*Electrical Charge*	*Remarks*
Alpha	α	Particle	4.00276 mu	+2	Identical to helium atom stripped of its electrons.
Beta	β	Particle	0.00548 mu	−1	Identical to a high speed electron.
Gamma	γ	Wave	None	None	Electromagnetic wave of energy.

Nuclear stability is determined primarily by the number of neutrons relative to the number of protons in the nucleus. For those isotopes having low atomic numbers, maximum stability is obtained when the n/p ratio is about 1. As the atomic numbers get larger, this ratio increases to about 1.5. When the number of neutrons in the nucleus differs greatly from the optimum ratio, the atom is radioactive. Radioactive elements up to a mass number (A number) of 80 are usually beta and gamma emitters, while those over 210 are alpha emitters. Where the n/p ratio is below the range for maximum stability, a positron ($\beta+$) may be emitted. A positron has the mass of an electron but is positively charged.

Nuclear reactions can transmute one element into another. The bombardment of nitrogen by alpha particles having the proper energy produces a stable isotope of oxygen and a proton and is illustrated by the equation:

$$\underset{\text{Stable}}{_7N^{14}} + {_2\alpha^4} \longrightarrow \underset{\text{Stable}}{_8O^{17}} + {_1p^1}$$

Energy may be imparted to nuclear missiles in particle accelerators such as cyclotrons, synchrocyclotrons, and bevatrons.

Capture or loss of a particle by the nucleus leads to the formation of a new isotope. If this isotope has an excess of nuclear energy, it is radioactive. It becomes stable after this surplus energy is released.

The conversion of mass to energy is explained by Einstein's famous theory of relativity. This relationship is represented by the equation, Energy = Mass times a constant, which is the square of the speed of light, ($E = mc^2$); if E is measured in ergs, m is in grams, then c is the velocity of light in centimeters per second. The following equation shows that an extremely small change in the mass of a system produces a very large amount of energy:

Equation:

Boron 10 + alpha → Carbon 13 + proton + E
where E represents the energy released

Eq. in Symbols:

$$\underset{\text{Nucleus}}{_5B^{10}} + {_2\alpha^4} \longrightarrow \underset{\text{Nucleus}}{_6C^{13}} + {_1p^1} + E$$

Mass in mu:

$$10.01344^* + 4.002764 = 13.004222^* + 1.007575 + E$$
$$14.016204 = 14.011797 + E$$
$$0.004407 = E$$

Energy equivalent; $E = 4.1$ Mev.

*The mass of a nucleus is smaller than the combined masses of the individual particles. The difference represents binding energy of the nucleus.

The difference in mass on the two sides of this equation is 0.004407 mass units which is transformed to energy. In this case the energy is equal to about 4.1 million electron volts (Mev). This might be compared to the energy of about 15-20 electron volts obtained from burning a single molecule of gasoline.

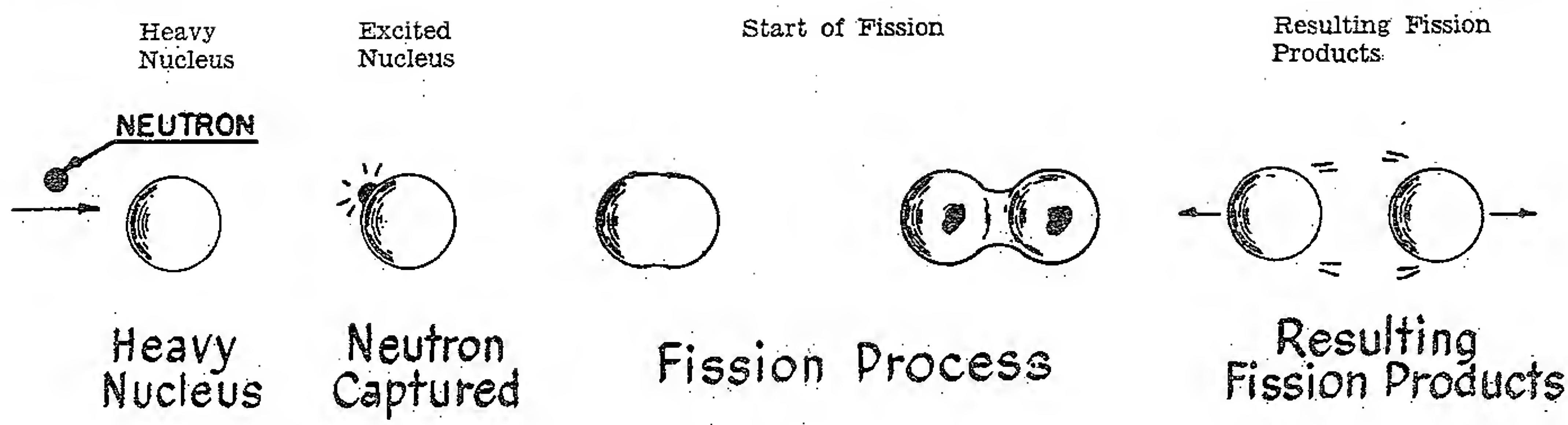

Figure 3—Fission Process.

Fission Process

The neutron is electrically neutral and is not repelled by the electrostatic field surrounding the nucleus. Therefore, it is more easily captured by the nucleus than a charged particle.

The bombardment of a heavy element such as uranium with neutrons may result in a reaction in which the nucleus splits into smaller nuclei with the release of a relatively enormous amount of energy. This is called fission. Although theoretically it is possible to obtain fission energy from all elements heavier than silver, practically, only uranium, plutonium, and thorium are useful for this purpose.

When fission takes place and a heavy nucleus breaks into lighter nuclei—called fission products—the energy released is about 200 Mev. About 0.1% of the mass of the uranium atom is converted into energy. The energy released from fissioning 1 kilogram of U^{235} is about 8 x 10^{20} ergs, equivalent to the energy produced by burning about 3,500 tons of high grade coal. The fission process is illustrated in Figure 3.

The fission process results in random splitting of the nucleus. Usually two, but sometimes three, fission products are produced. More than 200 fission products have been identified. Figure 4 shows the mass distribution of fission products. Most of them are radioactive. The radioactive fission products decay to stable atoms by emitting beta and gamma rays. Fission products are not alpha or neutron emitters.

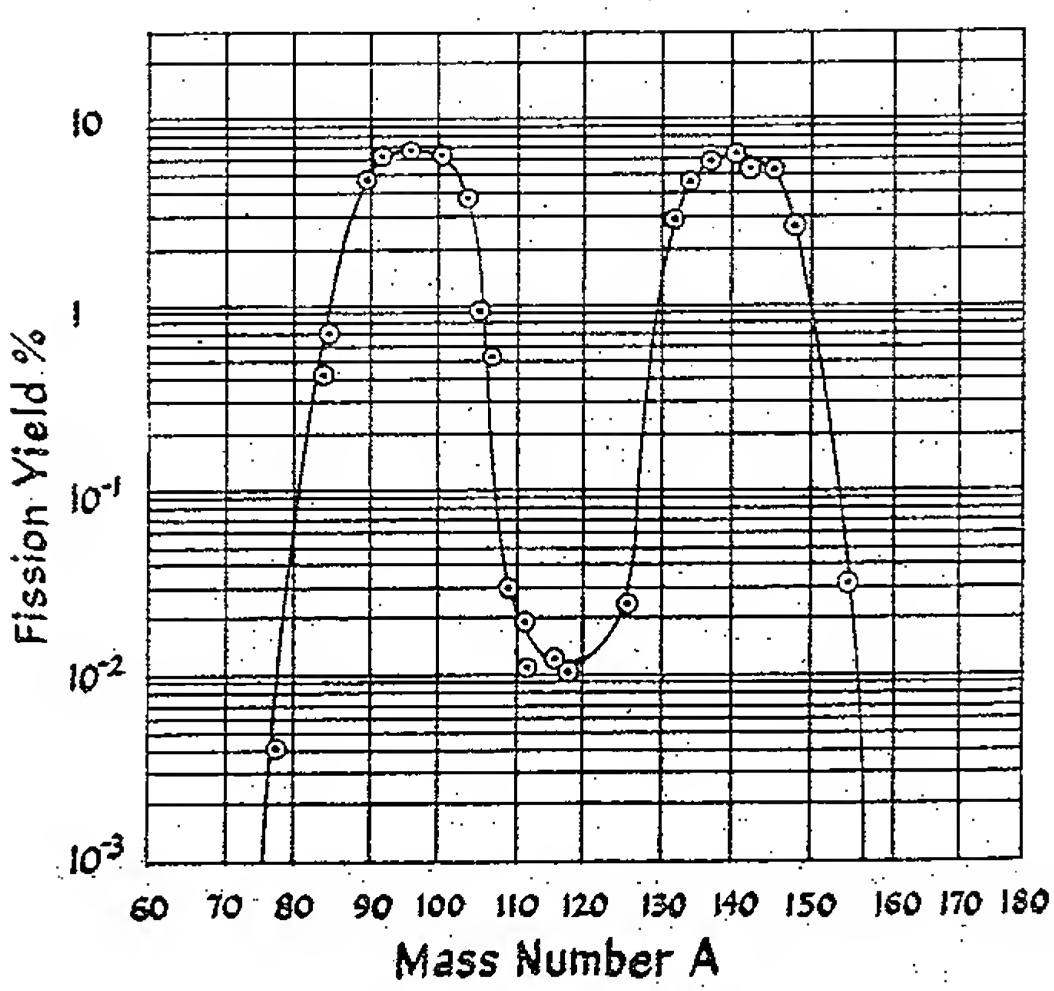

Figure 4—Mass Distribution of Fission Products.

THE ATOMIC BOMB

Fission is accompanied by the release of neutrons. The neutrons in turn may be captured by other nuclei and cause successive fissioning. This chain reaction (Fig. 5) makes possible the nuclear reactor and atomic bomb. In the reactor or pile, the fission rate is controlled by absorbing some of the neutrons. In the bomb, the reaction is not slowed and the chain reaction is completed in a fraction of a second.

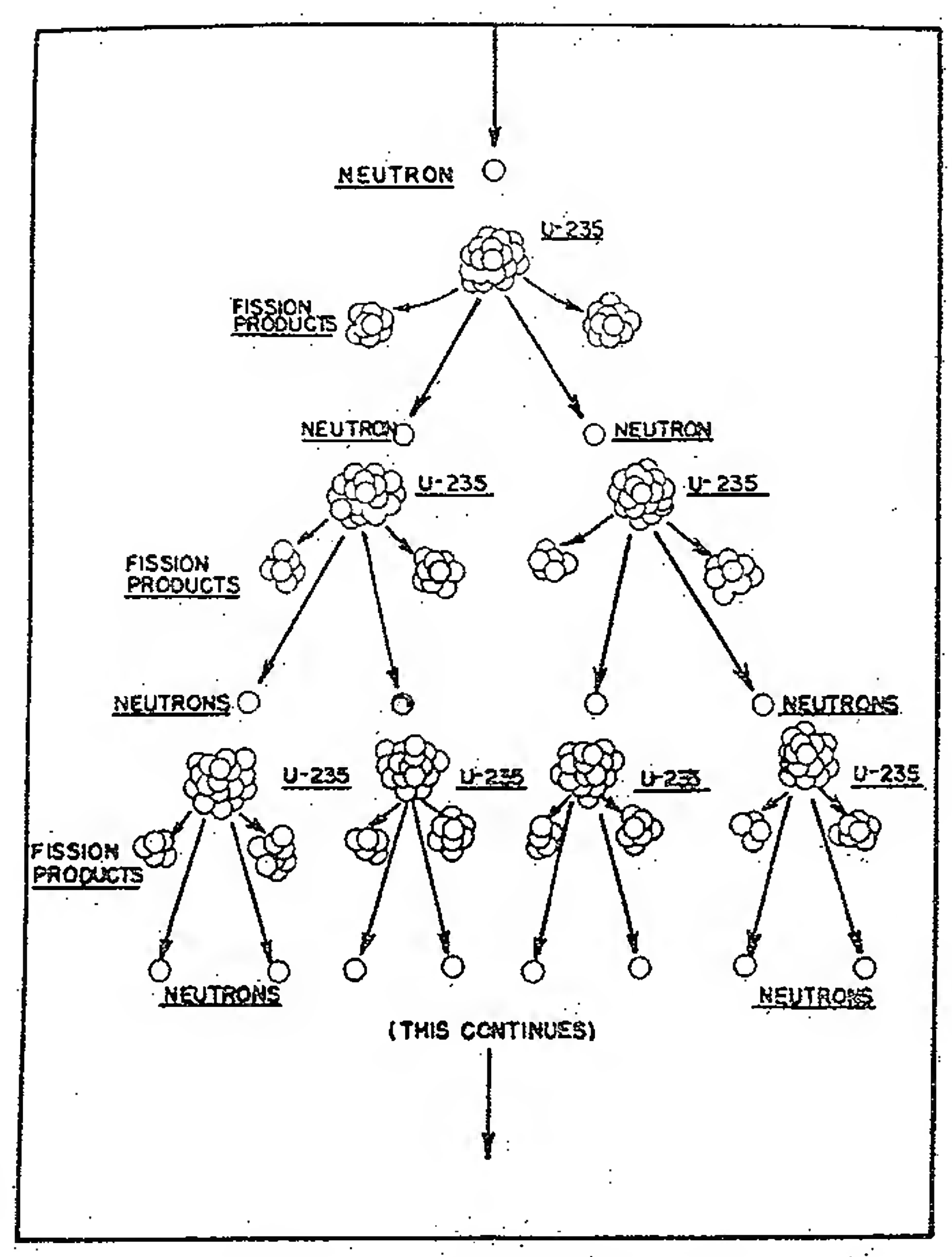

Figure 5—Diagram of Chain Reaction.

Energy released from the explosion of an atomic bomb produces the same three effects as an explosion of TNT; light, heat, and blast. In addition, the emission of nuclear radiation occurs. *Initial* radiation is composed of neutrons, gamma, and beta radiation, and lasts for about one minute after the detonation. The beta radiation, because of its short path length, does not contribute to the hazard. *Residual* radiation is gamma and beta rays from the fission products, alpha particles from the unfissioned uranium or plutonium, and beta and gamma radiation from substances made radioactive by neutrons released at the time of burst.

When a ground burst occurs, debris and dirt are sucked into the ascending cloud. Vaporized fission products, bomb fragments, and neutron-induced radioactive elements condense on this material. These contaminated particles which settle to the ground are called fallout. High air bursts do not produce significant fallout hazard because surface material is not carried into the cloud for the radioactive particles to condense upon.

Fusion

The fusion process, in contrast to the breaking up a heavy nucleus as is done in fission, combines two nuclei of light elements into a heavier one. Such reactions may be used to produce energy. The fusion process is the source of solar energy and requires temperatures of millions of degrees. The following equation is an example of the fusion reaction:

Equation:

Hydrogen 3 + Hydrogen 1 ⟶ Helium 4 + Energy

Eq. in Symbols:

$$\underset{\text{Nucleus}}{{}_1H^3} + \underset{\text{Nucleus}}{{}_1H^1} \longrightarrow \underset{\text{Nucleus}}{{}_2He^4} + E$$

Mass in mu:

$$\begin{aligned} 3.016472 + 1.008123 &= 4.002764 + E \\ 4.024595 &= 4.002764 + E \\ 0.02183 &= E \end{aligned}$$

Energy Equivalent:

$$E = 20 \text{ Mev.}$$

THE THERMONUCLEAR BOMB

Because the fission bomb produces the high temperature required for the fusion process, it serves as a trigger for the fusion device. The term "hydrogen bomb" has been used because one possibility for the bomb is based on the fusion of isotopes of hydrogen.

The same type of initial and residual radiation results from the thermonuclear bomb as with the fission weapon, but to a greater degree. A thermonuclear bomb will probably be detonated so that it touches the ground. Great quantities of surface material would be taken up into the cloud for the vaporized fission products and bomb fragments to condense upon. This greatly increases the fallout problem.

Multiple Decay

Each radioactive isotope has a characteristic half-life. These range from a few millionths of a second to millions of years. However, when many elements—in this case the fission products of a bomb—are present, no one half-life applies for the composite. With fission products there is a predominance of short-lived radioisotopes in the period immediately following the burst; hence the radiation level falls off very rapidly. As these expend themselves, the longer half-life isotopes become more dominant and the decay rate of the fission products decreases.

Multiple radioactive decay for fission products may be calculated by using Kaufman's equation for multiple decay, $K = IT^n$, where K = dose rate at unit time; I = dose rate at any time T, measured from the time of burst, and n is the Kaufman exponent. (Fig. 6). Time may be measured in any units—minutes, hours, days, weeks, etc. A more familiar form of this equation is $I = I_1 t^{-n}$. Where I is the activity at any time t, I_1 is the dose rate at unit time, and n is the Kaufman exponent. The value of n is not fixed; it may vary with bomb design, location of burst, and the amount and type of neutron-induced activity. For a particular contaminated area, decay may be affected by weathering and decontamination. For planning purposes, a value of n = 1.2 may be used. Accurate information on the radiation levels and rate of decay must depend on radiological surveys. (See table 1, appendix A.)

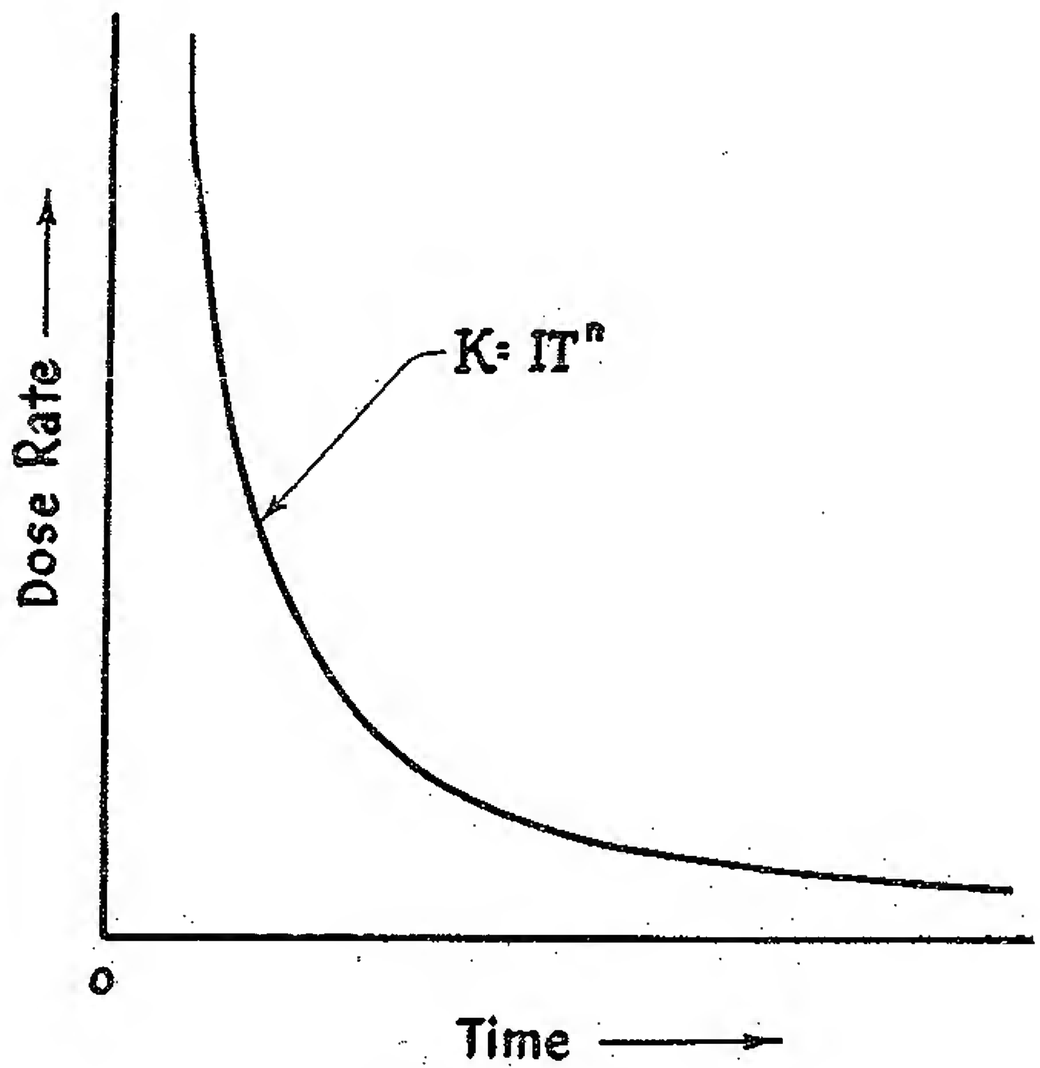

Figure 6—Multiple Decay.

Cumulative Dose

The total cumulative radiation dose and the time period in which it was received by a person is important when deciding if a person should be further exposed in civil defense operations. Dose is equal to the dose rate multiplied by time of exposure. (Dose = Dose rate x Time). This is easy to calculate when the radiation level remains essentially constant over a long period of time, as it does with a long-lived radioactive isotope.

In calculating dose from fallout radiation, the rapid decrease in radiation level must be taken into account. From the equation $D = \dfrac{K}{n-1}\left[t_1^{1-n} - t_2^{1-n}\right]$, the dose accumulated between the time of entrance (t_1) into a contaminated area and time of exit (t_2) can be calculated. D is the dose received, K = Intensity at unit time, and n is Kaufman's constant. (See appendix A.)

The percentage of total dose accumulated during a portion of the exposure time, is shown in Table 3.

Table 3—Accumulated Dose

Total dose received in:	Percent total dose for following exposure time in hours												
	4	8	12	16	20	24	36	48	72	96	120	336	720
(hours)	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
4	100												
8	78	100											
12	69	88	100										
16	64	82	92	100									
20	60	78	88	95	100								
24	58	74	84	91	96	100							
36	53	69	78	84	89	92	100						
48	51	65	74	80	84	88	95	100					
72 (3 days)	48	61	69	75	79	82	89	94	100				
96 (4 days)	46	59	66	72	76	79	86	90	96	100			
120 (5 days)	45	57	65	70	74	77	83	88	93	97	100		
336 (14 days)	40	51	58	63	66	69	75	79	84	87	90	100	
720 (30 days)	38	48	55	59	62	65	70	74	79	82	84	94	100

(Assuming n = 1.2 and the exposure starts 1 hour after burst)

For example: If the total dose were received in 48 hours, over ½ of it was received in the first 4 hours of exposure. If the total dose were received in 14 days, over half was received in the first 8 hours and about 75% in the first 36 hours.

Detection and Measurement of Radiation

Generally, instruments measure an effect of a phenomenon rather than the phenomenon itself. The sensitivity of radiation instruments depends on the ionizing effect of radiation. Most of these instruments measure the amount of ionization produced in a gas. Ionization of a gas consists of the removal of one or more electrons from one or more of the gas molecules, changing the electrically neutral molecules into positive ions. Civil defense survey meters and self-reading dosimeters are instruments of this type. In the presence of an electrostatic field, these positive ions are moved in one direction while the electrons are moved in the opposite direction. The measurement of the amount of current thus created, provides an indication of radiation level. Usually a closed tube having an electrically conducting shell and insulated central electrode, containing a definite volume of gas, is used as the radiation sensitive element of the instrument. Other instruments such as the phosphate glass and chemical dosimeters depend on ionization phenomena which change their molecular arrangement and consequently their optical characteristics.

GEIGER COUNTER

The geiger tube is filled with inert gas such as neon or argon and small amounts of organic or halogen vapor. The amount of ionization produced inside the tube by the primary radiation is amplified by the inert gas in an avalanche effect producing a pulse of current which activates an electric circuit. The organic or halogen vapor acts to terminate the pulse and restore the tube to its sensitive condition. Geiger counter instruments are useful for many purposes because of their sensitivity. Their primary use in civil defense operations would be for monitoring food, water, and people for radioactive contamination. They are particularly adaptable for training since they can be operated in weak radiation fields minimizing radiation exposures to trainees. Geiger counters do not read true dose rates in roentgens per hour unless measuring a known radiation energy for which the instrument has been previously calibrated. They read numbers of ionizing events without regard to the energy of these events. From a practical standpoint in civil defense, true roentgen readings in the low radiation levels for which a geiger counter is used are not important. The FCDA geiger counter, CD V-700[1], is calibrated against radium or cobalt 60 gamma radiation and will not give a true dose rate in roentgens per hour for the lower energy gamma radiation given off by fallout.

IONIZATION CHAMBER SURVEY METER

Ionization produced in the radiation sensitive chamber of the instrument is measured directly with an extremely sensitive electronic circuit. Electric current produced by this ionization passes through extremely high value resistors developing voltages which are fed into the grid of a special vacuum tube and amplified. Since minute currents are involved, special insulators, large value resistors and "electrometer" tubes are required.

Collecting all of the ions produced becomes a problem especially on the higher ranges. If the batteries are weak, the instrument may calibrate accurately at low readings but indicate less than the actual value in higher fields. For this reason, the batteries supplying the ionization chamber must be up to their rated value, particularly if the instruments are to be used in high radiation fields.

The instruments, CD V-710 and CD V-720[1] are ionization chamber survey meters. CD V-710 measures gamma only; the ionization chamber is protected by sufficient material to completely absorb alpha and beta radiation. CD V-720 may be used to detect gamma radiation only, or with its sliding shield in the open position, it responds to beta radiation as well. The instrument does not indicate beta radiation directly since the contribution from a gamma component will have to be subtracted. Even then a calibration chart must be used for proper interpretation.

DOSIMETER

The self reading ionization chamber dosimeter may be described as an electrical condenser in parallel with a high impedance voltmeter. The condenser is charged to give a

[1] See TB-11-20, Sept. 1955. Radiological Instruments for Civil Defense.

"zero roentgen" indication on the voltmeter. Radiation entering the sensitive chamber of the dosimeter produces ions which are collected by the electrodes of the chamber causing a reduction in voltage. The amount of this reduction is indicated on the meter as a particular radiation exposure. In the CD V-730 and CD V-740[1], "zero roentgens" correspond to about 170 volts while "full scale" corresponds to about 110 volts. The ionization chamber dosimeter requires exceptionally good insulation, since the instrument must be capable of holding its charge when no radiation is present. This requires insulation many million times better than that required in an ordinary radio. Dosimeters must be capable of accurately indicating the doses received at extremely high rates. Two factors may cause difficulties: (1) not all of the ions are collected or (2) the insulators lose ability to hold the electric charge, resulting in an apparent dose reading. Dosimeters produced in accordance with FCDA specifications do not exhibit these characteristics.

Glossary

Following are terms commonly used in radiological defense:

Absorption—The process by which the energy of radiation is reduced as it passes through matter. Absorbed radiation may be transformed into matter, other radiation, or energy by interaction with the electrons or nuclei of the atoms with which it reacts.

Absorption Coefficient—The fractional decrease in the intensity of a beam of radiation per unit thickness or unit mass of the absorbing material.

Alpha Particle—Nuclear radiation consisting of two protons and two neutrons and having a double positive charge. It is identical to a helium nucleus. Alpha particles can be stopped by a few inches of air, by a sheet of paper, or the dead surface layer of the skin.

Alpha Emitters—Radioactive materials which emit alpha particles. Certain of these substances have an affinity for bone tissue, have long half lives, and tend to remain in the bone for long periods of time. They are therefore dangerous if taken into the body, since the emitted alpha particles can cause cell damage in the immediate area where the substances become located.

Avalanche—A process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules.

Beta Particle—A negatively charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to an electron. Beta radiation may penetrate about a half a centimeter into the skin producing an effect similar to a burn. Beta particles are more highly ionizing.

Beta Emitters—Radioactive materials which emit beta particles. These substances taken internally can cause serious cell damage.

Curie (c)—The amount of radioactive material which decays at the rate of 3.7×10^{10} disintegrations per second. A millicurie (mc) is one thousandths of a curie; a microcurie (μc) one millionth.

Electron Volt (ev)—The amount of energy gained by an electron in passing through a potential difference of one volt. A million electron volts is abbreviated Mev. 1 Mev equals 1.6×10^{-6} ergs. 931 Mev equals 1 atomic mass unit.

Erg—A unit of work or energy. A million ergs equals 0.1 watt-seconds. A billion ergs equals 24 calories.

Gamma Rays—Short wave length electromagnetic radiations emitted from the nucleus of an atom. They have no mass or electrical charge. They may travel several thousand yards in air, and can completely penetrate the body.

Half-life, Physical—The time required for a radioactive substance to lose 50% of its activity by decay. Each radioactive isotope has its own characteristic half-life; it ranges from a millionth of a second to billions of years.

Ion—An atomic particle, atom, or group of chemically combined atoms that have an electric charge, either positive or negative.

Ionization—The process by which a neutral atom or molecule acquires either a positive or negative charge. A high speed particle passing through matter may cause the atom or molecule to divide into positive and negative parts called ions, destroying the electrical balance. (Fig. 7).

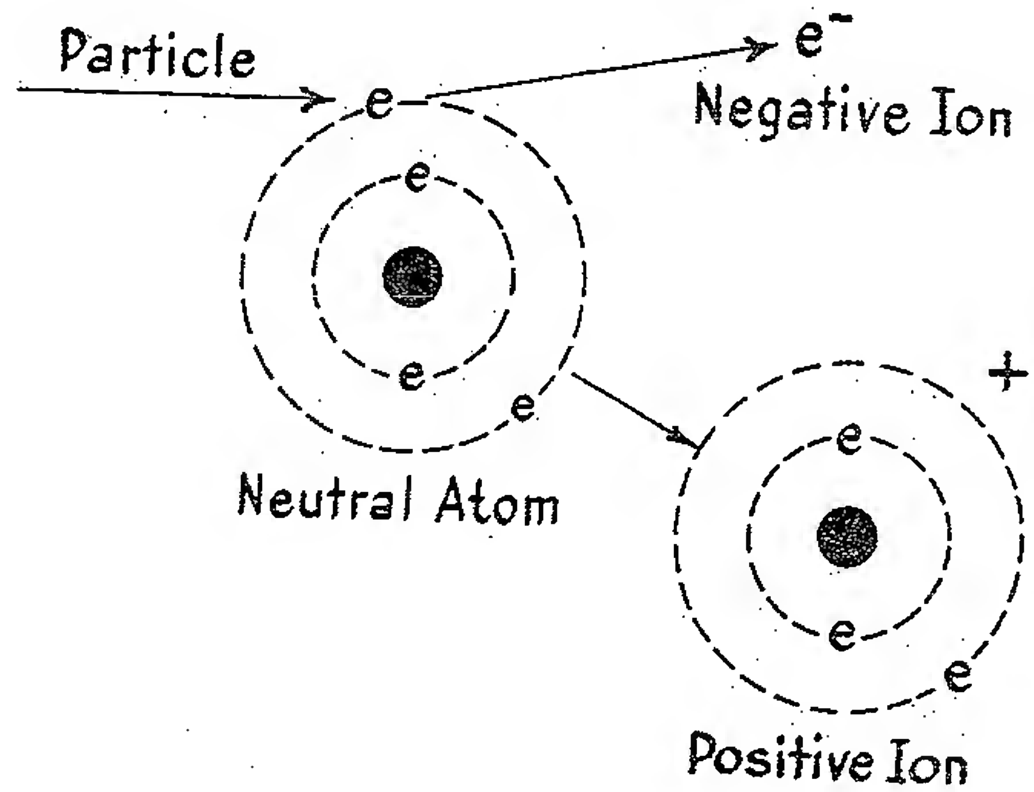

Figure 7—Ionization.

Ionizing Radiation—Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly. Gamma rays, beta and alpha particles, and neutrons are ionizing radiations of concern in radiological defense.

Neutron—Electrically neutral particle having a mass approximately the same as the hydrogen atom. Neutrons are released in the processes of fission and fusion. They are not emitted by radioactive fallout particles.

Residual Radiation—Nuclear radiation emitted by radioactive materials produced by the explosion of a weapon and including unfissioned bomb material.

Rigged Bomb—A nuclear bomb to which an element, such as cobalt, is added to increase neutron-induced radioactivity for the purpose of increasing contamination by fallout. The Department of Defense has called the cobalt bomb "impractical."

Roentgen—A unit of radiation quantity, defined as that amount of X- or gamma radiation which produces one electrostatic unit of charge of either sign in one cubic centimeter of air at standard temperature and pressure.

X-rays—Penetrating electromagnetic radiations identical to gamma rays, but generally less energetic. X-rays originate in the electron structure of an atom and may be produced by the sudden slowing down of high speed electrons as in the X-ray machine, or by the "jumping" of electrons from an outer to an inner orbit.

APPENDIX A

Calculating Dose From Fallout Radiation

Example:

What dose would a civil defense team receive due to a nuclear burst if the team entered a contaminated area 5 hours after the burst and the team stayed for a period of 16 hours. The dose rate at one hour after the burst was 50 r/hr.

Solution:

Using the formula found on page 4.

$$D = \frac{K}{n-1}\left[t_1^{1-n} - t_2^{1-n}\right]$$

$n = 1.2$
K = Intensity at unit time
t_1 = Time of entry
t_2 = Time of exit
D = Dose received in r.

By substituting values in the above formula

$$D = \frac{50}{1.2-1}\left[5^{1-1.2} - 21^{1-1.2}\right]$$

$$= \frac{50}{.2}\left[5^{-0.2} - 21^{-0.2}\right]$$

Referring to table 1 of appendix A, we find that:

$5^{-0.2} = 0.725$
$21^{-0.2} = 0.544$

Therefore:

$$D = 250\,[0.725 - 0.544]$$
$$= 250 \times 0.181$$
$$= 45r$$

Table 1

t = Time in hours	$t^{1.2}$	$t^{-0.2}$
0.1	0.0631	1.586
0.2	0.1450	1.381
0.3	0.2358	1.273
0.4	0.3330	1.202
0.5	0.4352	1.149
0.6	0.5417	1.110
0.7	0.6518	1.074
0.8	0.7651	1.046
0.9	0.8812	1.023
1.0	1.000	1.000
1.5	1.627	0.921
2.0	2.300	0.871
2.5	3.003	0.826
3.0	3.737	0.803
4.0	5.278	0.756
5.0	6.899	0.725
6.0	8.586	0.697
7.0	10.33	0.679
8.0	12.13	0.660
9.0	13.96	0.644
10.0	15.85	0.631
11.0	17.77	0.619
12.0	19.73	0.608
13.0	21.71	0.599
14.0	23.74	0.590
15.0	25.78	0.582
16.0	27.86	0.574
17.0	29.28	0.567
18.0	32.09	0.560
19.0	34.23	0.555
20.0	36.41	0.550
21.0	38.61	0.544
22.0	40.82	0.539
23.0	43.06	0.534
24.0	45.31	0.530
25.0	47.59	0.525
25.5	48.74	0.523
26.0	49.89	0.521
27.0	52.20	0.518
28.0	54.52	0.514
29.0	56.87	0.510
30.0	59.23	0.505
31.0	61.61	0.503
32.0	64.00	0.500
33.0	66.41	0.497
34.0	68.83	0.494
35.0	71.27	0.491
36.0	73.72	0.488
37.0	76.18	0.486
37.5	77.43	0.484
38.0	78.66	0.483
39.0	81.15	0.480
40.0	83.67	0.478
41.0	86.17	0.476
42.0	88.70	0.474
43.0	91.23	0.472
44.0	93.79	0.470
45.0	96.35	0.467
46.0	98.93	0.465
47.0	101.5	0.463
48.0	104.1	0.461
49.0	106.7	0.459
49.5	108.0	0.458
50.0	109.3	0.457
55.0	122.6	0.449
60.0	136.1	0.441
65.0	149.8	0.434
70.0	163.7	0.427
72.0	169.4	0.425
75.0	177.8	0.422
80.0	192.2	0.417
85.0	206.7	0.412
90.0	226.5	0.407
95.0	236.2	0.402
96.0	239.2	0.401
100.0	251.2	0.399
120.0	312.6	0.384
140.0	376.2	0.372
144.0	389.1	0.370
160.0	442.5	0.362
168.0 (1 wk)	468.1	0.360
180.0	508.5	0.354
200.0	577.1	0.347
250.0	754.3	0.333
300.0	938.7	0.319
336.0 (2 wk)	1075.0	0.313
504.0 (3 wk)	1745.0	0.288
672.0 (4 wk)	2471.0	0.272
720.0 (1 Mo.)	2611.0	0.268
1440.0 (2 Mo.)	6166.0	0.234
2160.0 (3 Mo.)	10031.0	0.216
4320.0 (6 Mo.)	23045.0	0.187
8640.0 (1 Yr.)	52943.0	0.163
17280.0 (2 Yr.)	121640.0	0.143
25920.0 (3 Yr.)	197860.0	0.131
34560.0 (4 Yr.)	279430.0	0.124
43200.0 (5 Yr.)	365240.0	0.118
86400.0 (10 Yr.)	839100.0	0.102
216000.0 (25 Yr.)	2519700.0	0.086

APPENDIX B

Graphical Solution of Dose From Fallout Radiation

Example:

Using the same example as given in appendix A the solution by graph is as follows: See chart 1 of appendix B.

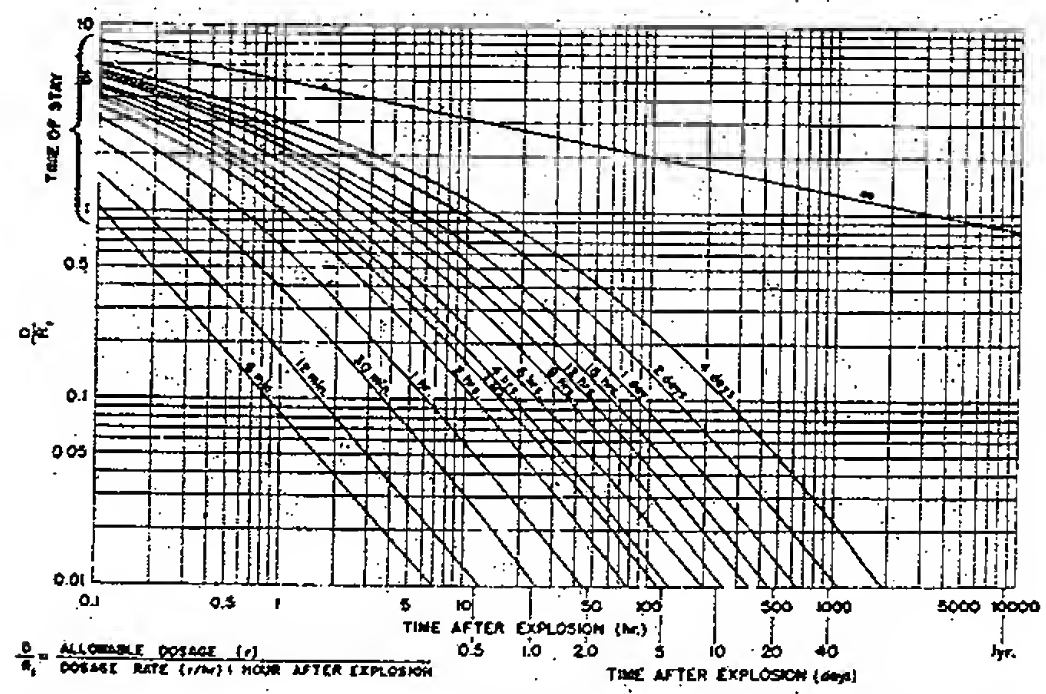

Chart 1

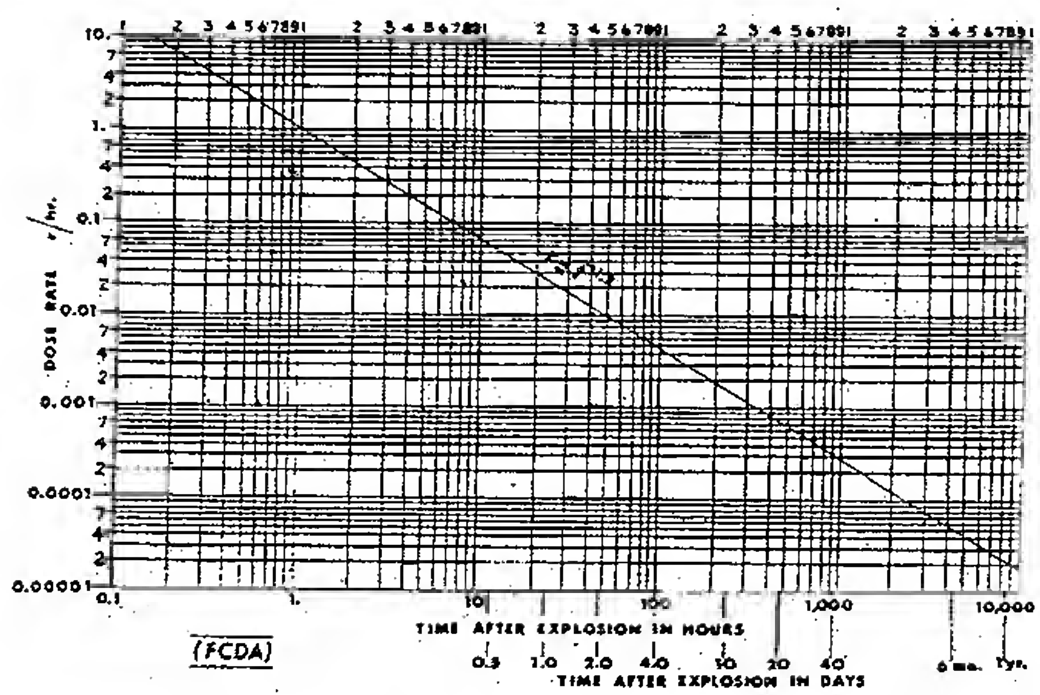

Chart 2

Solution:

The point of intersection of the 5 hour **after the explosion** line and the 16 hour **time of stay** line lies on the $\frac{D}{R_1}$ line and equal to .9

D = Dose (r)

R_1 = Dose rate (r/hr) 1 hour after explosion

$$\frac{D}{R_1} = .9$$

or

$$D = .9 \times R \text{ or } .9 \times 50 = 45 \text{ r}$$

To determine the approximate dose rate at H+1:

1. Determine the time after explosion of your measurement.
2. Locate the point of intersection with time after explosion line (chart 2) and the decay line, $r = t^{-1.2}$. Read the dose rate (r/hr) on the left axis.

Example:

A radiological monitor records a reading of 6.3r/hr at 10 hours. What was the dose rate H+1.

Solution:

$$\text{Dose rate (r/hr) at H+1} = \frac{\text{meter reading at specific time}}{\text{Value read from chart 2}}$$

$$= \frac{6.3}{.07}$$

$$= \text{Approximately 90 r/hr}$$

To determine the approximate dose rate at any time:

Example:

If the meter reading is 6.3 r/hr at H+10, what will the dose rate be at H+20?

Solution:

$$\frac{\text{Dose rate (r/hr) as measured}}{\text{Dose rate (r/hr) at new time}} = \frac{\text{Dose rate (r/hr) from chart 2 at time of measurement}}{\text{Dose rate (r/hr) from chart 2 at time selected}}$$

By substitution:

$$\frac{6.3}{\text{Dose rate at H+20}} = \frac{.07}{.03}$$

Cross multiplying:

$$\text{Dose rate at H+20} = \frac{.03 \times 6.3}{.07}$$

$$= 2.7 \text{ r/hr}$$

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